

Dislocation induced ac Josephson effect in high- T_c superconductors

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A possible scenario for an ac Josephson effect initiated by the flow of dislocations through a mechanically loaded but electrically unbiased superconductor is proposed. The characteristic voltages due to the motion of dislocations in loaded (under the applied stress of 10^7 N/m^2) *YBCO* crystals are estimated to be of the order of a few picovolts which corresponds to the Josephson frequency of 10 kHz .

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According to recent experimental observations [1-5], high- T_c superconductors (HTS) possess a large number of extended defects which give rise to the various interesting phenomena in these materials [6-11]. In particular, considering a twinning boundary (TB) as insulating region of the superconductor-insulator-superconductor (SIS) structure [6], the possibility of dislocation-induced dc Josephson effect in HTS has been recently discussed [10,11]. At the same time, using the so-called method of acoustic emission (see, e.g., Ref.12), a quite tangible motion (flow) of twinning dislocations in HTS crystals (at $T < T_c$) under external load has been registered [13-15].

Based on these experimental findings, in the present paper a possible scenario for an ac Josephson effect related to the external load induced flow of dislocations through an electrically unbiased superconducting sample is proposed and its realization in HTS crystals is discussed.

As is well-known [16], a constant voltage V applied to a Josephson junction causes a time evolution of the phase difference between two superconductors, $d\theta/dt = 2eV/\hbar$. As a result an ac Josephson current occurs through such a contact

$$I_s^V(t) = I_c \sin(\theta_0 + \omega_V t), \quad (1)$$

where θ_0 is the initial (at $t = 0$) phase difference, $\omega_V = 2eV/\hbar$ the Josephson frequency, and I_c the critical current.

In the present paper we discuss another possibility for ac Josephson effect which is due to the external load (σ) induced flow of dislocations through an unbiased ($V = 0$) superconducting sample. Namely, we assume [10,11] that initially (at $t = 0$) there is a twin boundary (which is characterized by a non-zero dislocation-induced deformation ϵ [8]) inside a superconductor which creates a SIS type single junction Josephson contact. When a mechanical stress is applied to the system, causing a flow of dislocations (and thus the corresponding displacement of the insulating layer which is created by these dislocations, see Fig.1) through a loaded crystal, a time-dependent phase difference $d\theta/dt = (d\theta/d\epsilon) \dot{\epsilon}$ [where $\dot{\epsilon} = d\epsilon/dt$ is the rate of plastic deformation under an applied stress] is expected to occur in such a *moving* contact. For simplicity, in the present paper we postulate a linear dependence for the induced phase difference assuming $\theta(\epsilon) = A\epsilon$ (where $A \simeq 1$ is a geometrical factor). To stay within a short junction approximation (for which Eq.(1) is valid), we assume also a constant (time-independent) rate of flow of dislocations through a loaded crystal. Finally, taking into account the dependence of $\dot{\epsilon}$ on the number of dislocations (of density ρ) and a mean dislocation rate v_d , viz. [17] $\dot{\epsilon} = b\rho v_d$ (here b is the value of the Burgers vector), the dislocation-induced zero-voltage ac Josephson current reads

$$I_s^\sigma(t) = I_c \sin(\theta_0 + \omega_\sigma t) \quad (2)$$

Here $\omega_\sigma = b\rho v_d(\sigma) = 2eV_d(\sigma)/\hbar$, where $V_d(\sigma) = \hbar b\rho v_d(\sigma)/2e$ is a characteristic voltage due to the motion of dislocations, and σ is the external stress which causes the flow of twinning dislocations. Thus, comparing Eqs. (1) and (2), we conclude that one can observe a dislocation-induced ac Josephson effect either by applying a constant voltage to the (immobile) contact or, alternatively, by applying a mechanical stress to electrically unbiased but mobile [due to flow of dislocations (forming the insulating layer of SIS type contact) through the loaded crystal] Josephson junction. Regarding the latter possibility, it is interesting to mention that according to the Faraday's law of induction, a voltage induced in a closed circuit can be presented as a rate of magnetic flux flow through this circuit, namely $V_{ind} \propto d\Phi/dt$, implying a linear flux dependence of the phase difference through the contact, i.e. $\theta(\Phi) = 2e\Phi/\hbar$.

Since [17] $v_d \sim (\sigma/\sigma_m)^n$ with $n \simeq 1$ and σ_m being the so-called ultimate stress, according to Eq.(2) the ac Josephson effect due to flow of dislocations disappears when the external load is relieved ($\sigma \rightarrow 0$). At the same time, the dc Josephson effect can still exist provided there are enough dislocations in a superconductor to sustain the insulating (or normal metal) region for SIS (or SNS) type contacts [an explicit dislocation density dependence of the initial phase difference θ_0 and the critical current I_c of a dc effect has been discussed in Refs.10 and 11, respectively].

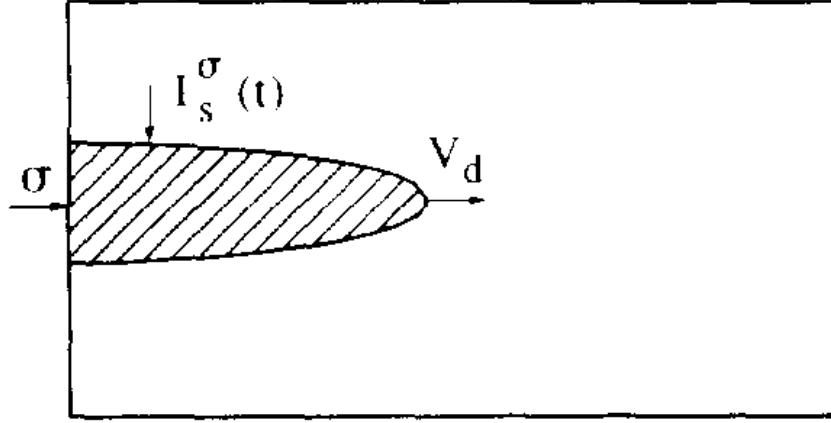


FIG. 1: Sketch (out of scale) of the dislocation induced ac Josephson effect geometry. The flow of twinning dislocations of density ρ (with $v_d(\sigma)$ being the rate of the growing twin boundary tip) under the external stress σ results in ac Josephson current $I_s^\sigma(t) = I_c \sin(\theta_0 + \omega_\sigma t)$, with the characteristic frequency $\omega_\sigma = b\rho v_d(\sigma)$ (the insulating region due to moving dislocations is hatched).

Let us estimate the order of magnitude of the dislocation-induced voltage V_d . To this end, we have to know the order of magnitude of the dislocation rate $v_d(\sigma)$. According to recent investigations [14,15], based on the method of acoustic emission [12], the flow of twinning dislocations with the maximum rate of $v_d = 0.1\text{m/s}$ has been registered in *YBCO* crystals at $T = 77\text{K}$ and under the external load of $\sigma = 10^7\text{N/m}^2$ [with the ultimate stress of $\sigma_m \cong 10^8\text{N/m}^2$]. Taking $\rho_m \cong 10^{14}\text{m}^{-2}$ and $b \cong 1\text{nm}$ for the maximum density of dislocations, and the magnitude of the Burgers vector in heavily dislocated *YBCO* crystals [5,8], we get $V_d(\sigma = 10^7\text{N/m}^2) = \hbar b \rho v_d / 2e \cong 1\text{pV}$ for the order of magnitude of the characteristic voltage due to the motion of dislocations, which is equivalent to the characteristic Josephson frequency $\omega_\sigma \cong 10\text{kHz}$. It would be quite interesting to observe the above-discussed effect in dislocated HTS crystals experimentally.

In summary, a possible scenario for an ac Josephson effect originating from the external load induced flow of dislocations through an electrically unbiased superconducting sample has been proposed. The characteristic Josephson frequency due to the motion of dislocations in loaded (under the applied stress of 10^7N/m^2) *YBCO* crystals is estimated to be of the order of 10 kHz.

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